Challenges to Biology

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BIOLOGY, in contrast to physics and chemistry, has until now concerned itself with the phenomena on Earth. But with the possibility of examining the nearby planets at first hand the biologist will soon face a wider perspective. He will have an opportunity to seek answers to the intriguing question of whether extraterrestrial life exists, and from studies of other planets, he may gain information on the origin of life on Earth. Moreover, the biologist will have a new and serious responsibility, not just to science but to the world as a whole, arising from the possibility that there may be biological consequences of space exploration itself.

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In order to ask whether life occurs on another planet we must provide ourselves with a definition of "life." The consensus so far, derived from our knowledge of Earth life, is that any definition of life must be arbitrary; that is, if life has gradually evolved from inanimate matter, the demarcation between nonliving and living is a matter of judgment. Many biologists seek a convenient working definition of life in the fact that life exhibits the unique capacity to become more complex with time, i.e., to evolve. A system to be described as alive must be able not only to reproduce itself but also to mutate, i.e., to undergo randomly introduced alterations which are then reproduced. In any particular environment, individuals having certain combinations of characteristics will reproduce more rapidly than others and thus predominate. In time the species will have altered, adapting to the environment—which is evolution. The complexity that individuals can achieve is determined by the range of possible mutations, and if the range itself can be increased by mutation there are no foreseeable limits to the complexity that can be reached.

In the last few decades we have learned that all life on

Earth has fundamentally the same chemical basis. All forms of Earth life depend upon an aqueous environment, and on moderate temperatures that permit organic macromolecules to be reasonably stable. Furthermore, they are all composed of similar molecules. We now know that two of these, the nucleic acids and the proteins, account for the most basic activities we associate with life. The proteins serve as specific catalysts, directing cellular chemical reactions that produce the chemical substances needed for growth. Proteins are constructed of relatively small subunits called amino acids, of which there are 20 different kinds, arranged somewhat like links in a chain. A typical protein may be composed of several hundred amino acid units ordered in a sequence specific for this protein.

Any organism must be able to make thousands of different protein molecules, and it derives information for their structures from its genetic endowment. It is now known that desoxyribonucleic acid (called DNA) forms the essential chemical basis of this endowment. DNA has the remarkable property of being able to contain information to duplicate itself. From its structure, discovered by Watson and Crick, and from experimental studies, it is becoming apparent how DNA can carry out these functions. It is made up of four different subunits (nucleotides), with hundreds of nucleotides forming a long chain. It is believed that the arrangement of the four different types of nucleotides in a particular nucleic acid determines by some coding relationship the arrangement of amino acids in a particular protein. Furthermore, the DNA molecule is built of two complementary long nucleotide chains wound about each other; the sequence in one chain determining the sequence in the other. It is believed that each chain of a pair provides information for the formation of a new complementary chain; thus one pair of chains can make two pairs.

Mutation can occur if a wrong nucleotide is put in at some point. Such a change would lead to an alteration in the protein specified by this nucleic acid and would be perpetuated in the progeny. This relationship between nucleic acids and proteins forms the basis of all known Earth life, and the discovery of this relationship is a major triumph of biology. But much remains to be learned of the actual chemical mechanisms involved.

The origin of life has been the subject of much thought since the earliest speculations of man. A major early milestone in the development of biology was the demonstration that the suspected cases of spontaneous generation of life from inanimate matter were false and that recognizable life apparently always develops from an earlier parent. This led to the idea that prevailed for many years that life had its origin on Earth in some extremely unlikely accident.

But more recent ideas have lent encouragement to the belief that there is a good, rather than unlikely, chance for life to develop on a planet like Earth. It was argued that spontaneous chemical processes would lead to the formation of many complex molecules. In fact, amino acids are formed by the action of electric discharges on gas mixtures similar in composition to the presumed primitive atmosphere of Earth. In the absence of voracious organisms such complex compounds would accumulate, especially in the oceans where they would be protected from the decomposing action of solar radiation. In this "soup" there could develop self-replicating structures that would catalyze their own formation. How this might have happened is not yet understood in any detail but we are beginning to visualize the essential conditions for chemical replication. Much is being learned from biochemical studies of nucleic acids and from industrial syntheses of stereo-specific polymers. It is possible that ancient rocks may yield "chemical fossils" from this early period in the evolution of life on Earth which would help toward an understanding. Probably, these will be hard to find since most such relics have been destroyed on the Earth's surface by later occurring life and beneath the surface by the action of high pressures and temperatures.

One intriguing theory of the origin of life, which now seems less credible but which is difficult to rule out completely, is the hypothesis of panspermia advanced by the physical chemist Svante Arrhenius. He suggested that life originated on Earth through the migration of spores to Earth from some other planet. But it is difficult to account for the escape of a spore from a planet, and the idea that light pressure could give sufficient velocity to permit escape from the gravitational field of a planet as large as Earth or any planet large enough to sustain a significant atmosphere is implausible except for objects the size of the smallest viruses. Moreover, assuming that a spore did escape from a planet, the intense solar radiation prevailing in the absence of a protecting atmosphere would destroy it in a tiny fraction of the time required to go from one planet to another. Finally, the hypothesis of panspermia only defers the problem of the origin of life to some unknown site. Nevertheless, considering future developments in rocketry, it would not be wise to rule out completely the possibility of an artificial panspermia where life itself evolves the means for making an interplanetary voyage.

From our present understanding of terrestrial life we can deduce some minimal conditions for life of any kind to exist. There must be a chemical system in an environment where large information-bearing molecules are stable; and in addition there must be a source of energy and a source of chemical raw materials in order that the information-bearing molecules can duplicate themselves. Further, the development of life would almost certainly depend on the presence of a liquid solvent like water in which chemical reactions would proceed far more rapidly than in the dry state.

Extraterrestrial Life

On the basis of this picture of Earth life and of the mechanism of its origin, the biologist has many questions he would like to ask. Principally, of course, he wants to know whether life exists outside the Earth. Should any be discovered, the biologist's first wish would be to gain an understanding of the chemical basis of this life. Does it, like Earth life, use the protein-nucleic acid system? If not, what chemical systems are used for information storage and catalysis? Along with the search for life there is the additional important objective of finding, through studies of the chemistry of planetary surfaces, evidence that might help us understand better surfaces, evidence that might help us understand better the chemical evolution which led to the appearance of life on Earth.

Early missions will have severe limits on the weight of experimental apparatus that they can carry and on the amount of information that they can return to Earth. It will have to be decided whether to gamble for a quick answer with a "long shot" experiment or use the early space probes for gathering more precise and certain information as a basis for the design of more sophisticated experiments. It does appear, however, that a popular choice for an early mission making a "soft landing" will be a visual examination of the surface of a planet. It is a thrilling prospect to examine closeup photographs of the surface of a planet like Mars, and such pictures should also serve as valuable guides for the design of later experiments. With great luck a closeup might give convincing evidence of Martian life. Along with chemical stains which give specific colors with substances like nucleic acid and protein, this photographic equipment could also be used to identify the chemical basis of any life that might be discovered. Moreover, such stains, when employed with a microscope, might permit the detection of small organisms that otherwise could escape notice.

Planetary Evaluation

Of the nearby planets Mars offers the best chance of finding life. Although water and oxygen are scarce, the range of temperatures on Mars is moderate; and in fact, there are a number of Earth micro-organisms which would certainly be able to survive in the Martian environment. Whether they could actively proliferate will probably depend on the local availability of moisture; obviously a map of Martian humidity would be a crucial objective of early exploration, as water may be the most prized mineral on the planet.

There is a long record of speculation on whether or not life exists on Mars. Much of the evidence has been at best only suggestive. Recent observations of the infrared reflection spectrum of Mars appear to indicate the presence of C-H molecules in the dark areas, materials whose abundance seems to vary with the seasons. An urgent objective is the further study of this phenomenon, and a probe to the near vicinity of Mars could provide crucial data unobtainable from Earth.

Venus seems less likely to contain a recognizable form of life. Its surface temperature is apparently higher than the boiling point of water, according to indirect determinations from radio wave measurements. However, as in the case of Mars, it would be intemperate to make dogmatic conclusions until we have mapped the planet in more detail. In the case of Venus, with its dense atmosphere, a three-dimensional map of temperature and moisture is needed to indicate the zones where life might exist.

The Moon, barren of atmosphere, appears unlikely to harbor life. But we know nothing of the conditions beneath its exposed surface.

The Moon may be especially interesting as a gravitational trap for meteoroidal material accumulated from space over many eons, unaltered by the action of atmosphere. The Earth is the most likely source of such material; and should terrestrial material be identified on the Moon, it would furnish strong support for the hypothesis of panspermia. Mercury appears much like the Moon physically. Its dark side, perpetually free from the corroding effects of the solar radiation, may be a far better repository of meteoroidal material than the Moon, although its distance makes it a less likely target.

The large planets are too distant for early examination, but they are not without interest. Conditions there would favor the accumulation of organic material. Compounds formed in the chemically reactive conditions of the upper atmosphere would descend to lower altitudes where they would be shielded by the atmosphere from decomposition by the solar radiation. It has been calculated that by now enormous quantities of carbon compounds have accumulated on the large planets.

Like all advances in human technology, space exploration may create new problems for mankind; and the biologist must be prepared to contribute toward minimizing them. One source of concern can already be anticipated. A consequence of our ability to send vehicles to other planets is the infection of these planets with Earth life. A probe, for example, could introduce microbial life onto a planet; and if there were nothing to limit growth, the organisms could occupy the entire planet in days or weeks. By the time a later probe was sent it would be too late to study the planet in its virgin condition, denying us an inestimable prize for the understanding of our own life and its origins. Moreover, we cannot exclude the possibility that such a catastrophe would have economic repercussions as well; it would be rash to predict too narrowly the ways in which undisturbed planetary surfaces might serve human needs. Also we must face the conceivable moral problems raised by the thought of our contaminating an already inhabited planet.

Fortunately, the responsible agencies in the U.S. and in the USSR have recognized this problem and will insist that due precautions be taken on planetary missions. Vigorous methods of decontamination of spacecraft, principally by gaseous fumigation, are being developed. A conservative policy can do no harm, and caution need not preclude enthusiastic exploration.

By the next decade vehicles may be making round trips to the planets, and we must reckon with the bizarre possibility that the returning vehicles may infect Earth with life from some other planet. Since the very existence of extraterrestrial life is still speculative, we can only surmise what such back contamination might mean. There could be new plant or animal diseases. If nothing more, we could imagine serious competition for some essential resource from a life form of extraterrestrial origin. The probabilities of these occurrences cannot be guessed. We must protect ourselves, however, by designing and sending automatic instruments that will return information without the peril of invasion of Earth by some strange organism. In time, with more information on conditions on other planets, we will have a far better basis for deciding on the advisability of bringing materials from other planets to the Earth.

For the biologist, space research is a gamble against high odds for higher stakes. The experiments are difficult to design, requiring years of preparation, and very likely the results will be negative. But there is the tantalizing prospect of finding answers to some of the oldest and most basic questions of biology. It can be argued that biology could gain more from space exploration than any other major field of science. At the same time, the biologist has a unique and grave responsibility to consider the implications of space exploration for human welfare.